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Earthworms as Bioindicators of Soil Radioactive Pollution

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The use of various animals and plants as bioindicators has acquired much importance recently. Earthworms constitute the most significant invertebrate group (about 50% of the animal mass) in the middle USSR—their number may reach to several hundreds/m^2. Their importance also lies in their high sensitivity to soil radioactive pollution. In fact, in *Lumbricus terrestris*, $LD_{50/30}$ was estimated as 67.8 krad of gamma-irradiation (Reichle et al. 1972); similar values were also reported by Edwards (1969). In the enchytraeids and oribatids investigated by us, $LD_{50/30}$ was found higher than 100 krad, in collembols 125.6 krad (Styron 1973), in black wireworms 60-100 krad (Krivolutzky & Filippova 1979), while soil protozoa—nematodes, rotifers, tratigrades—survive at considerably higher irradiation doses.

Earthworms, as they also feed large quantities of mineral soil particles, are irradiated both from the surrounding radiation-polluted soil as also through the intestinal contents (Krivolutzky et al. 1978).

Soil sampling for invertebrate population, including earthworms, involved the standard technique as proposed by Ghilarov (1971). Soil samples (0.25m^2) were taken at depths below 30-40 cm and hand-lifted. 20-32 samples from each plot (5-8m^2) were taken; the figures represent only statistically significant indices.

In May 1974, an experimental plot of birch forest on grey forest soil was irradiated with a dose of 2.6 krad ± 30% employing a mobile powerful gamma unit with 32000 Ku ^{137}Cs (Karaban et al. 1977). Mesofauna counts in September, i.e. 4 months after irradiation, revealed that the number of earthworms declined from 66 (control) to 13 individuals/m^2 (irradiated plot), i. e. there occurred a five-fold decrease. Earthworms have proved to be the most radiosensitive group of soil mesofauna with statistically significant differences. Experiments were also performed with grey forest soil, polluted with products of uranium fission, primarily with ^{90}Sr. (Krivolutzky & Turchaninova 1969, Ghilarov & Krivolutzky 1971, Turchaninova & Tikhomirov 1973).

Mean data for seven years of field observations show that among permanent soil-dwelling invertebrates, earthworms are one of the most radioactive-pollution-sensitive groups. Apparently, lithobiids and geophylids, which are also sensitive to radioactive pollution, vary in number due to decline in the number of earthworms and Enchyticidae, which they consume, in the affected area but not directly through the action of radiation. How stable are the changes in soil invertebrate complexes, permanent dwellers of soil environment at all stages of life cycle, can be judged from their seasonal number dynamics during a field season.

The differences in the structure of soil animal dwellers have been dramatic as per the studies of increased natural radiation background. In fact, in middle taiga plots on sod-podzolic soils of floodland meadows with increased ^{226}Ra concentration, the earthworm population was markedly depressed. The plots (1–2 ha), situated at a terrace above floodland with middle taiga vegetation, were studied at an increased level of gamma-radiation (50–4000 mcr/hr). An increased radiation background was caused by the water flooding from underground layer with an increased Ra-content ($7.1.10^{-10}$–$5.6.10^{-11}$ g/g of annealed sample), in soils sod-podzolic. For comparison, plots similar in soil and vegetation to the experimental ones, were selected with a normal background of natural radiation. The soil-dwelling mesofauna invertebrates were studied by hand-lifting [samples 50 × 50 cm down to the layer where animals occurred (usually 30-40 cm)].

Statistically significant differences ($P = 0.99$) were obtained for all animals which show low mobility and also develop and live in the soil for a long time, that is permanent dwellers of areas with increased radiation background. Compared with controls, such plots demonstrated markedly lower numbers of earthworms, larvae of *Diptera* and *Elateridae*; also, there were significantly bigger (less) invertebrates.

Mobile surface arthropods (staphylinids, carabids, spiders, phalangids) showed no significant differences in number.

Earthworms proved particularly sensitive to increased ^{226}Ra. In fact, in mid-summer, the earthworms on plots with 100mcr/hr irradiation were 7 times lower than those in the control and smaller in size. There were some noteworthy changes in the reproductive process: in August, on the control plot, there were several young individuals, and on the polluted plot, they were almost absent. Evidently, on a polluted plot, young individuals grew and attained sex maturity later compared with those on control plots. In fact, in June when earthworms begin breeding, the control population was represented largely by sex-mature individuals but in plots with higher pollution levels, more than half of the population failed to achieve sex-maturity.

With *Dendrobaena octaedra* and *Dendrodrilus rubidus* as examples, the histological structure of the epithelium of integuments and mid-gut (the tissues which are in immediate contact with Ra-polluted soil) was studied in animals from control and Ra-polluted plots with a background of about 4000mcr/hr. Both the species are the dwellers in the most superficial soil layers. Earthworms collected from the Ra-polluted soil show marked changes in the structure of integumental epithelium (shape and size of mucous cells): the integumental cells are broader and considerably bigger—their number is considerably larger than that in the control with less cambial cells in the sections (Krivolutzky et al. 1978).

Further, some changes are noted in the structure of the mid-gut epithelium: there are markedly less enzyme-producing epithelial cells than mucous ones; and the numbers of regenerating units and cells in the thickness of epithelium are lesser compared to those in the controls.

In both the earthworm species dwelling on plots with an increased level of natural radiation (about 100–4000 mcr/hr), the epithelium of outer integuments and mid-gut was found to contain a significantly larger number of mucous cells and a higher level of mucous excretion, which appears to be a protective response to the effect of alfa-radiation.

A comparison of the present data with the data obtained previously for terrestrial vertebrates dwellers of the same plots (Maslov & Maslova 1972), showed that the general regularities are similar: the greatest irradiation effect was recorded in sedentary groups of animals inhabiting for a long time areas with an increased radioactive background; they showed an inhibited development and some disturbance in the functioning of the outer and intestinal epithelium. As to invertebrates of the soil, the effect of increased irradiation can be observed not only on plots with a very high radiation level (2000–8000 mcr/hr) but also with a much lower one (100–200 mcr/hr), the reason being that the soil animals have a close contact with Ra-contaminated soil. Earthworms are a very convenient subject for such studies because of irradiation both on the outside and by the soil swallowed. All other terrestrial invertebrates do not swallow soil for food, but plants or other animals in which the content of natural radionucleids is much lower than in the soil (by 1–2 order).

During the two field seasons, the effect of increased thorium background on soil mesofauna in middle taiga and mountain tundra was studied and investigations were performed from mid-July to mid-August. Sixty-four samples (50 × 50cm) were taken down at the depth where the animals occurred.

The animals were studied on two middle-taiga plots, similar in relief (hilly, with steepy slopes), vegetation (bilberry spruce forest) and soils (podzolic illuvial-humic and shallow surface glei) but differing in thorium content (in the soil). In control plots (radiation background 15–20 mcr/hr), thorium content was: in the litter $2.1.10^{-5}$ g/g; and on plots with increased thorium content (background 30–400 mcr/hr) $5.3.10^{-4}$ and (2–5). 10^{-5} g/g, respectively.

In mountain tundra, soil mesofauna was estimated in two plots similar in relief, vegetation, soils and thorium content. The results of these studies are in agreement with previous inferences: on the whole, soil invertebrates are good indicators of radioactive pollution, in the given case, of natural increased radiation background, but particularly marked are differences in the numbers of those groups of animals which are unable to migrate horizontally on a large scale, being permanent dwellers of radioactive soil.

Plots with increased thorium content where our studies were performed are well described in the literature (Maslov 1972). As in the above-described case, earthworms are a group, sensitive to change (increase) in the background of ionising radiations. It should be noted that soil animals do not accumulate natural radioactive elements or other heavy metals.

However, in all cases, earthworms are not a universal bioindicator of radioactive pollution as they are not abundant everywhere. In fact, no marked differences were found in the earthworm population in soils, experimentally polluted with ^{239}Pu (Krivolutzky & Fedorova 1973) and in plots with grey forest soils of forest-steppe with ^{238}U in an order higher than the background level as well as in plots with U-Ra-pollution. Common of all the plots were initially very low numbers of earthworms, and heavy anthropegine disruption of soil invertebrate complexes (because of forest fires, etc.). Apparently, under those conditions too, increased radiation background was detrimental to earthworms but this impact could have only been detected by studying particular animal individuals collected on experimentally polluted plots.

There is a ground to infer that earthworms are convenient bioindicators of any radioactive pollution of soil. It is especially promising to use them as a bioindicator where their numbers are adequately high and soil invertebrate communities are not disrupted by uncontrolled human impact. Under such conditions, earthworms in close contact with polluted soil begin to respond to ionising radiations earlier and to a greater extent than other terrestrial animals.

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